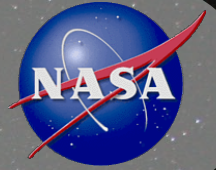


Spectral Characterization of Modern Spacecraft Materials

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[NASA Orbital Debris Program Office](#)



Acknowledgements

- **Jacqueline A. Reyes**
- **Elena Plis**
- **Ryan C. Hoffmann**
- **Gregory P. Badura**
- **Jainisha Shah**
- **Sydney Collman**
- **Daniel Engelhart**
- **Timothy R. Scott**



Agenda

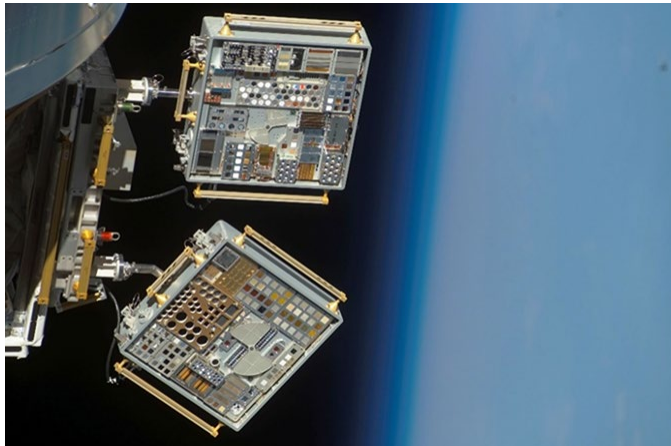
- **MISSE background/Motivation**
- **Samples investigated**
- **Laboratory/Facility Background**
- **Spectral Analysis**
- **Conclusion**

Materials International Space Station Experiment (MISSE) Flight Facility (MISSE-FF)

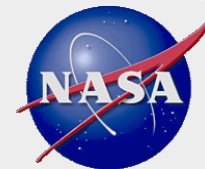


- **MISSE heritage**

- MISSE has flown nearly 4000 materials affixed to ISS starting in 2001
- Used to study harsh space environment in LEO
- Operated by Alpha Space Test & Research Alliance, LLC
- <https://www1.grc.nasa.gov/space/iss-research/misse/>



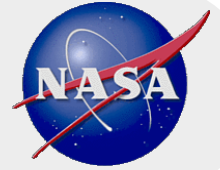
- **“Spectral Characterization of Novel Spacecraft Materials at LEO Environment”**
 - May 2022: Launch on SpX-25 (date subject to change)
 - June 2022: Approximate installation to MISSE facility
 - July 2022: Expected delivery of first on-orbit science data and photos
 - February 2023: Approximate return to Earth



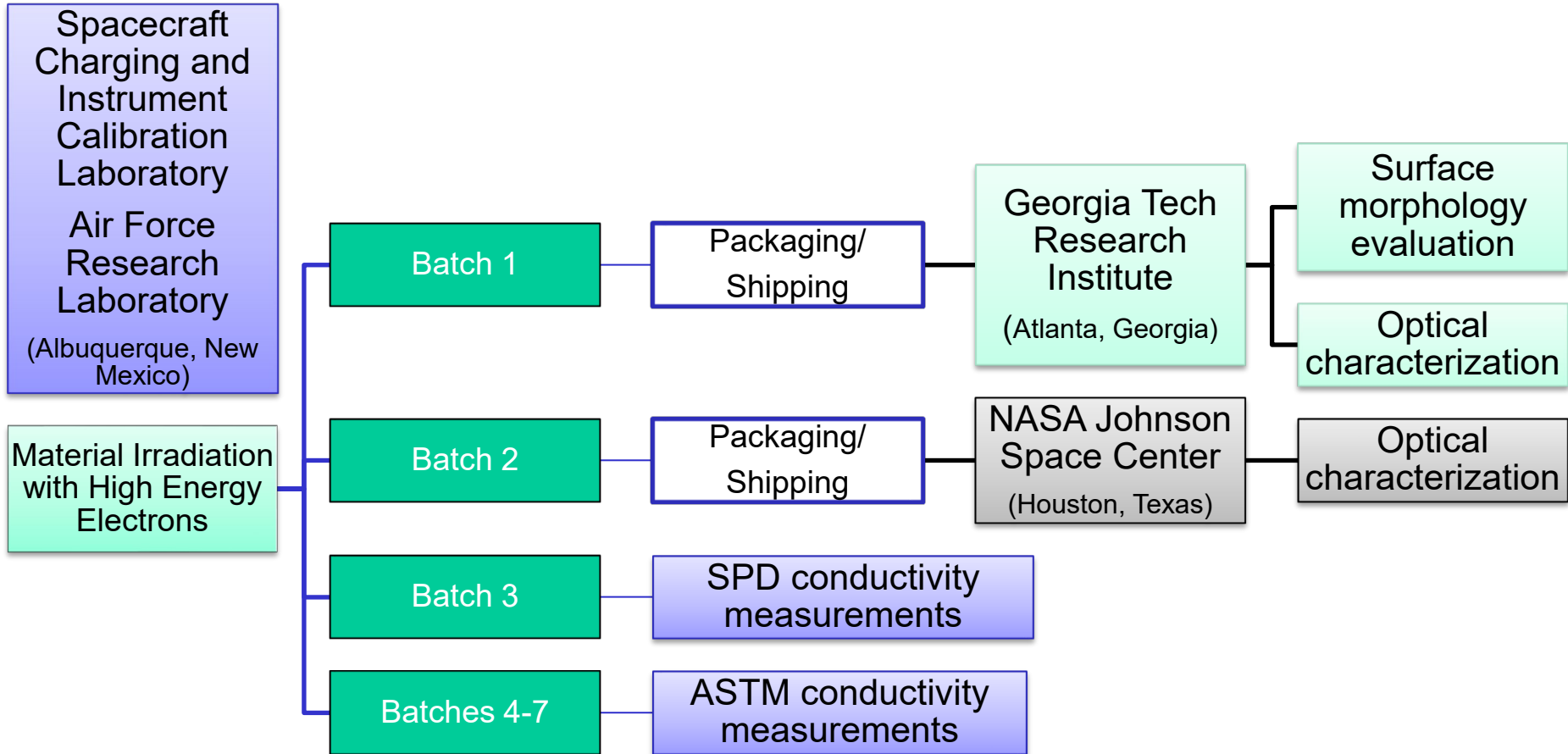
Samples Investigated

| ID | Name | Material Class | Density (g/cm ³) | Thickness (mils) |
|----|----------------------------|---------------------------------------------|------------------------------|------------------|
| 1 | Kapton® CR | Polyimide (PI)/(PMDA) | 1.54 | 2 |
| 2 | Kapton® CS | Polyimide (PI)/(PMDA) | 1.42 | 2 |
| 3 | Kapton® WS | Polyimide (PI)/(PMDA) | 1.42 | 1 |
| 4 | Kapton® XC | Polyimide (PI)/(PMDA) | 1.41 | 2 |
| 5 | Kapton® TF | Polyimide (PI)/(PMDA) | 1.42 | 4.0 |
| 6 | 200DR9 | Polyimide (PI)/(PMDA) | 1.42 | 2 |
| 7 | Kapton® HN | Polyimide (PI)/(PMDA) | 1.43 | 3 |
| 8 | Economyplate™ Carbon Fiber | carbon fiber reinforced polymer (CFRP) | 1.44 | 29 |
| 9 | G-10/FR4 Glass Epoxy | glass fiber reinforced polymer (GFRP) | 1.9 | 66 |
| 10 | Zenite® LCP | Liquid crystal polymer (LCP) | 1.75 | 3 |
| 11 | Melinex® 454 | polyethyleneterephthalate (PET) | 1.4 | 5 |
| 12 | Mylar® M021 | polyethyleneterephthalate (PET) | 1.39 | 9 |
| 13 | Corin® XLS | Polyhedral Oligomeric Silsesquioxane (POSS) | 1.40 | 0.6 |
| 14 | Thermalbright® N | Polyhedral Oligomeric Silsesquioxane (POSS) | 2.08 | 0.8 |
| 15 | Alumina | Aluminum Oxide (ALUM) | 3.95 | 3.8 |

Trade names and trademarks are used in this report for identification only. Their usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.



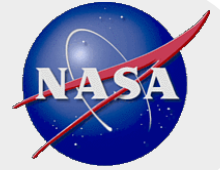
Sample Handling



Acronyms:

- SPD - Surface Potential Decay
- ASTM - American Society for Testing and Materials

Spacecraft Charging and Instrument Calibration Laboratory AFRL-Kirtland Air Force Base



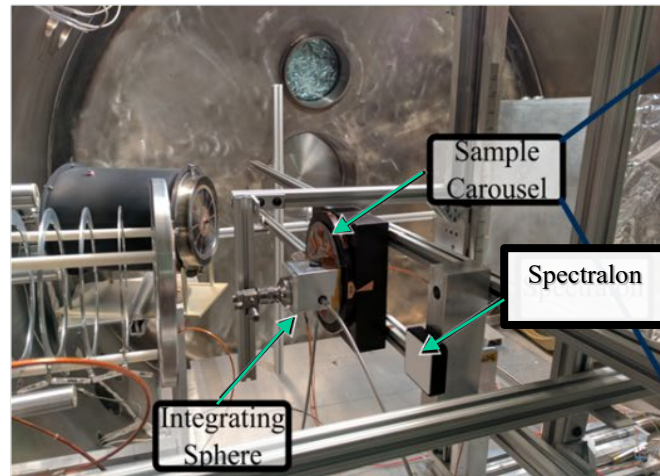
Electron Irradiation

• Jumbo Environmental Simulation Chamber

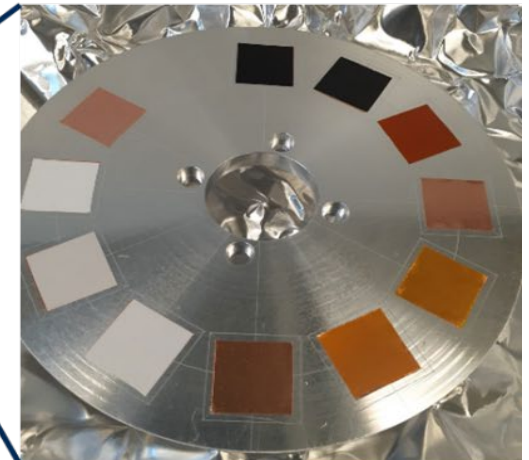
- 1.8 m × 1.8 m cylindrical chamber, capable of (10⁻³ torr) to high vacuum (10⁻⁶ torr) pressures
- Prime electron source is a Kimball Physics EG8105-UD electron flood gun with a range of 1 keV–100 keV, MISSE materials are irradiated with 100 keV electrons
- Samples are mounted on carousel and rotated during the high energy electrons bombardment to mitigate “hot spots” and provide equal doses
- *In-situ* Directional Hemispherical Reflectance measurements capability



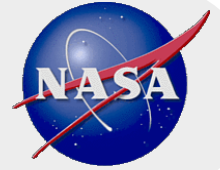
Credit: AFRL



Credit: AFRL



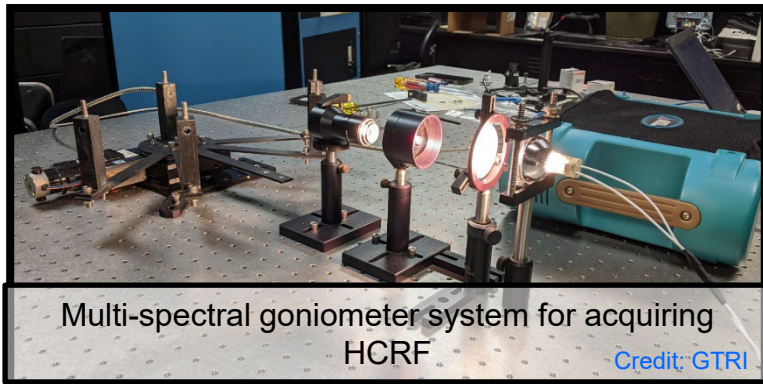
Credit: AFRL



Georgia Tech Research Institute

Optical characterization

- Thermo Nicolet™ 6700 Fourier Transform Infrared (FTIR) Spectrometer
- UV/Vis Cary 5000 Spectrometer
- Custom developed Hemispherical Conical Reflectance Factor (HCRF) measurements set up



- ASD FieldSpec Pro Spectrometer® Measures radiance from 350–2500 nm and has 20-degree solid angle
- Optical assembly for light source with blackbody source over range of 350–2500 nm and 5-degree solid angle

Surface morphology characterization

Atomic Force Microscopy (AFM)

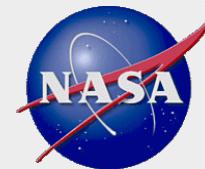


- Bruker Dimension ICON AFM located at Georgia Tech IEN/IMAT* Materials Characterization Facility
- Imaging at atomic level in contact mode, with less than 30 pm in tapping mode
- Allows to measure surface roughness up to 5 μm on areas as large as 200 $\mu\text{m} \times 200 \mu\text{m}$

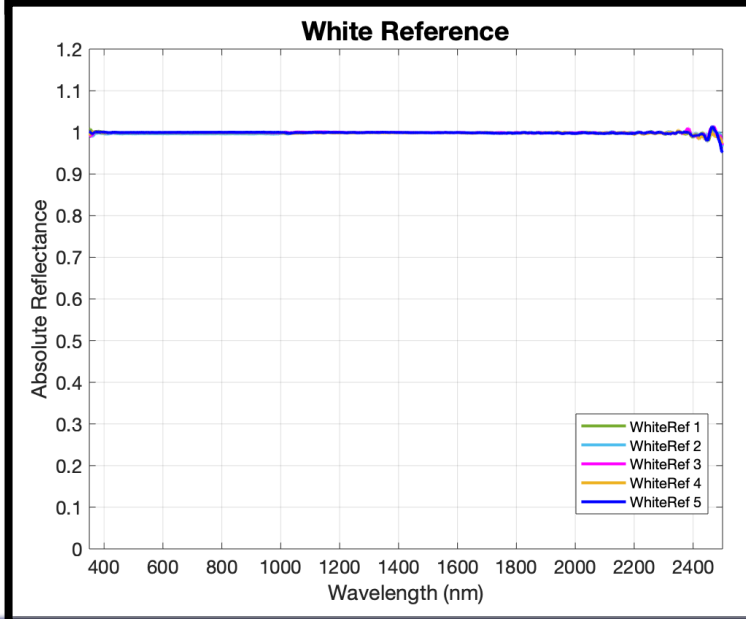
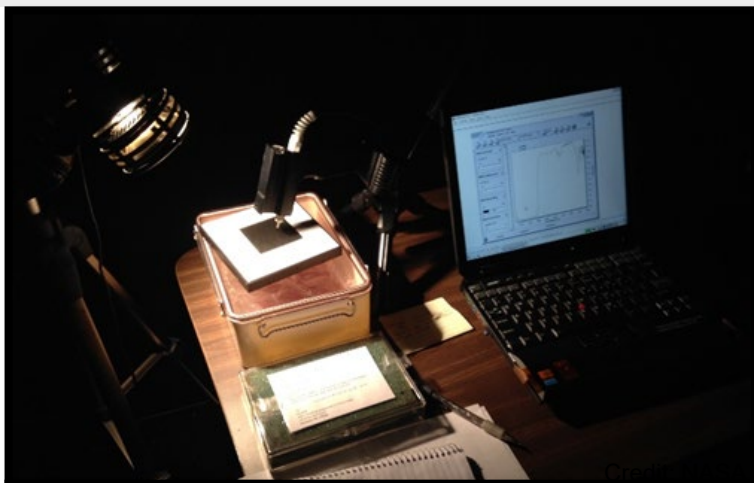
Scanning Electron Microscopy (SEM)



- Hitachi SU-8230 SEM located at Georgia Tech IEN/IMAT Materials Characterization facility
- The 8230 FE-SEM employs a novel cold field emission (CFE) gun for improved imaging
- The system is equipped with an Oxford EDS detector and has resolution of 0.8 nm @ 15 KV / 1.1 nm @ 1 KV.



Optical Measurement Center (NASA/JSC)



Credit: NASA

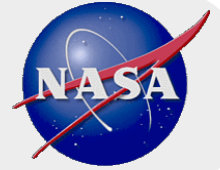
Optical Characterization- Reflectance Spectroscopy

- **Instruments:**

- Analytical Spectral Device (ASD) field spectrometer, ASD FieldSpec4, with a range from 350–2500 nm, FOV $\sim 25^\circ$
- Quartz lamp illuminator
- Spectralon®: white reference/calibration plate
 - Labsphere Lambertian Spectralon panel serves as calibration for a near perfect Lambertian reflectance source and is spectrally flat over the UV-VIS-NIR spectrum.

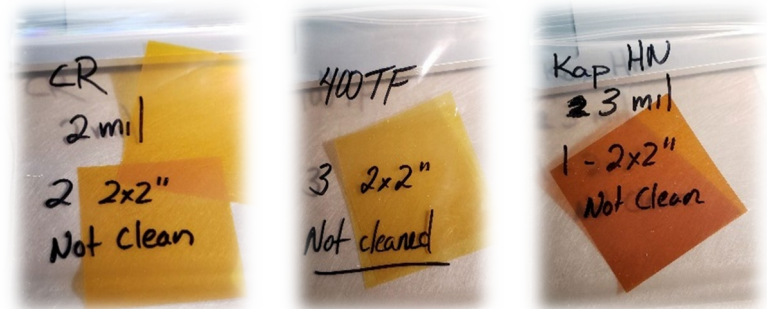
- **Environment:**

- Dark laboratory, no external lights/windows
- Dehumidifier and spot cooler to maintain requirements
 - Temp: Min: 32° F, Max: 86° F
 - Relative Humidity: Max 50% \pm 5%



Polymide (PI)/(PMDA)

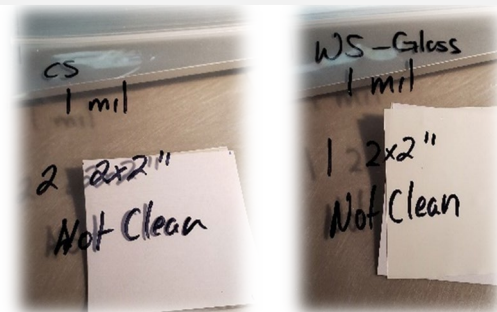
- Kapton CR – visibly copper colored
- Kapton TF – visibly copper colored
- Kapton HN – visibly copper colored



- Kapton XC – visibly black colored
- 200DR9 – visibly black colored

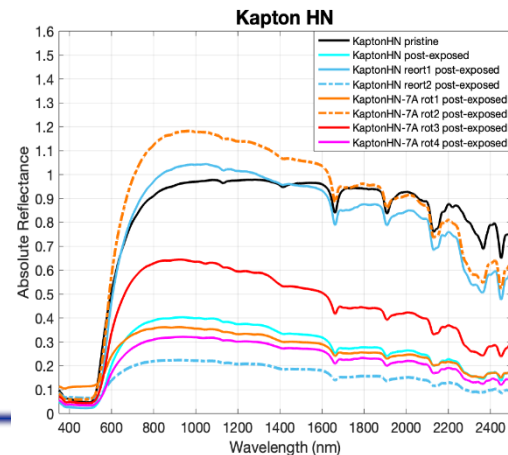
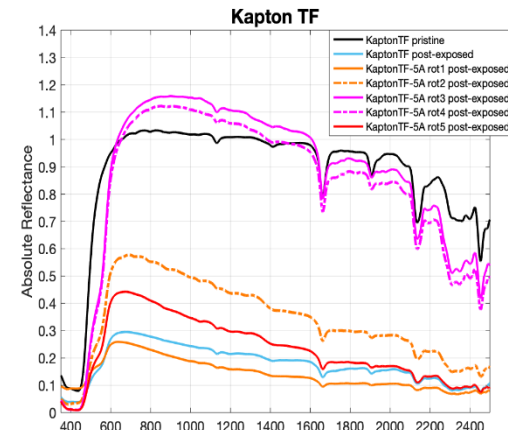
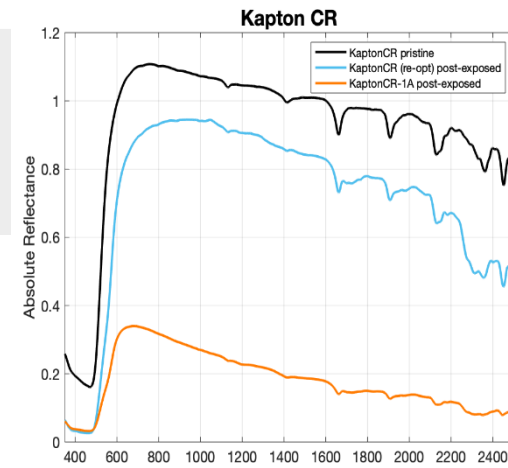


- Kapton CS – visibly white colored
- Kapton WS – visibly white colored



PMDA: CR, TF, HN

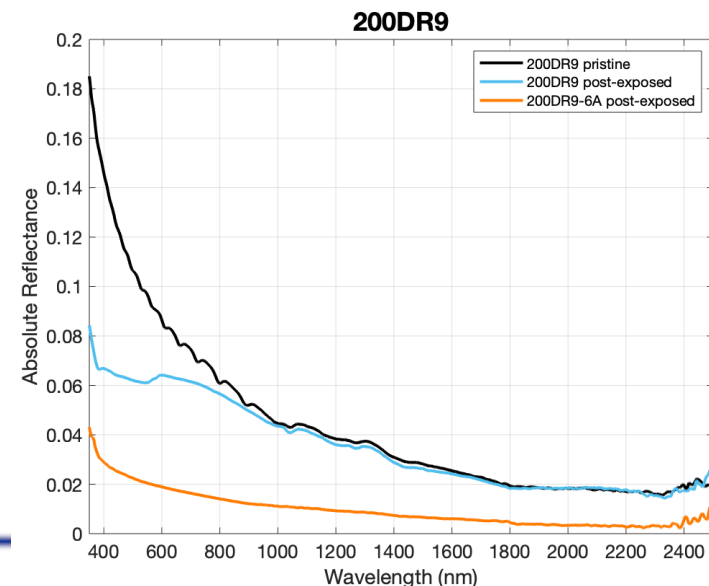
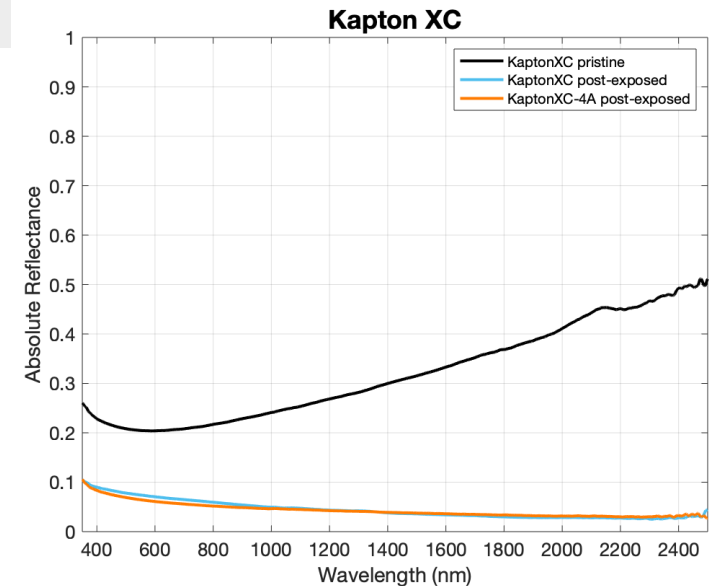
- All materials feature bandgap due to the amber or **copper color** near 450 nm – 600 nm
- Typical organic features noted: O-H 1400 nm and weak H₂O 1900 nm, C-H near 1650 nm and 2300 nm, C-H or O-H bond near 2100 nm (doublet), 2450 nm feature C-O or O-H bonds
- All samples highly reflective in pristine state
- Kapton CR shows decrease in reflectivity after electron bombardment
- Kapton TF and HN vary in reflectivity as the sample is rotated within the illumination beam, increased (specular, beyond calibration) and decreased reflectivity

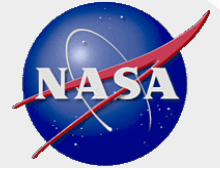




PMDA: XC, 200DR9

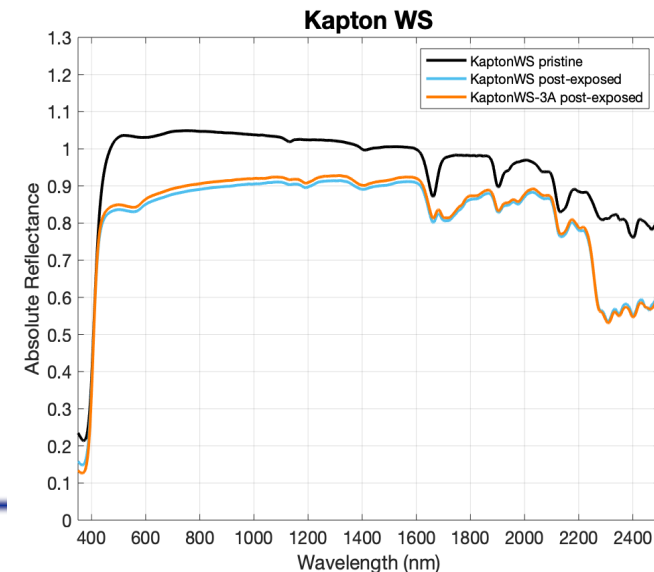
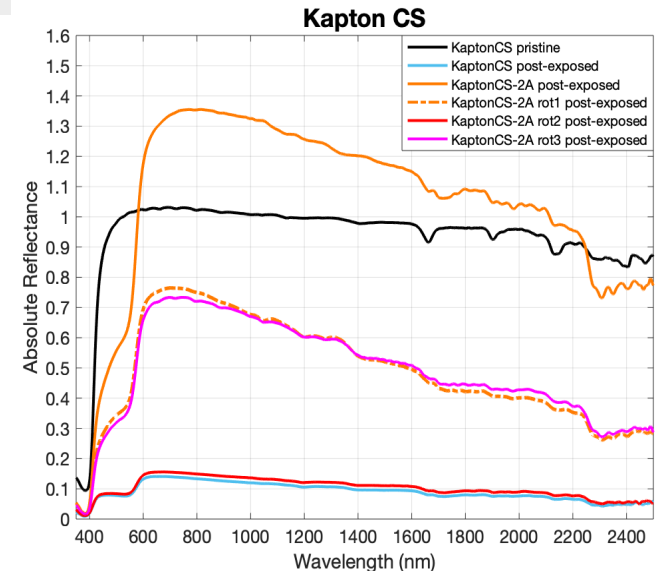
- Both samples indicate a featureless spectral response and have a low spectral response, indicative of black (light absorbing) materials, also both samples are 2 mil in thickness
- Kapton XC (pristine) reflectance increases with higher wavelengths, whereas 200DR9 has a near exponential decrease in the visible regime
- Both exposed samples show a decrease in reflectivity, ~55% in the visible regime, but beyond 800 nm, the delta for Kapton XC is 70-90%, whereas 200DR9 aligns with one of the exposed sample
- The feature between 400–600 nm in the exposed 200DR9 sample is due to the adhesive material





PMDA: CS, WS

- Both samples are optically white, as indicated with the sharp bandpass near 350–500 nm
- Kapton CS - the exposed material varies from exceeding 100% reflectance (specular) to a decrease of 25% or 85%, organic features harder to discriminate in exposed samples
- Kapton WS – C-H bond at 1650 nm changed from single to doublet in exposed samples
- C-H bond much deeper in exposed samples

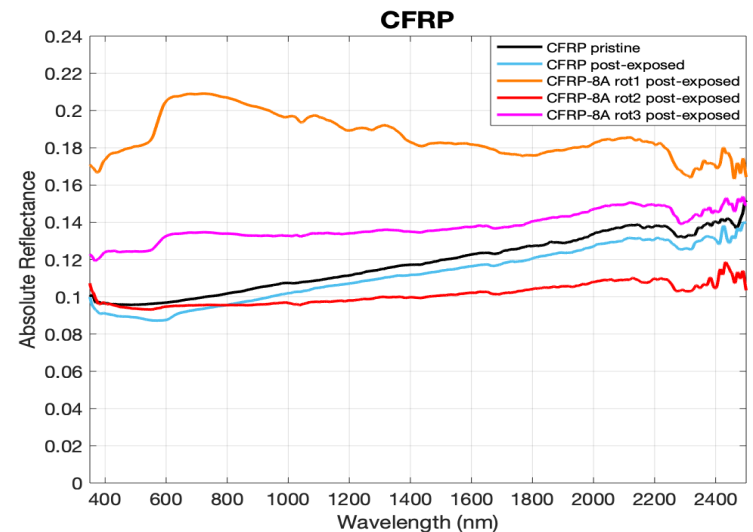


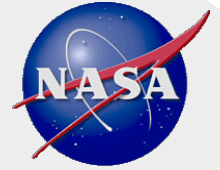


Carbon Fiber Reinforced Polymer (CFRP)

- **Economyplate™ Carbon Fiber**

- Modern-day material, relatively featureless
- Increasing spectral response for pristine measurements
- Variations in spectral reflectivity after electron-bombardment
- Feature between 400–600 nm likely attributed to 3M copper tape used as adhesive for experiment
- Exposure to electron-bombardment does not significantly affect material, but the placement of the sample post-exposure did factor into overall reflectivity (increase/decrease)

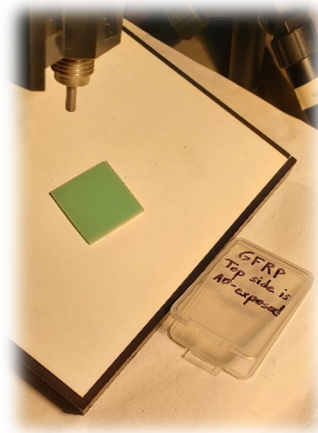




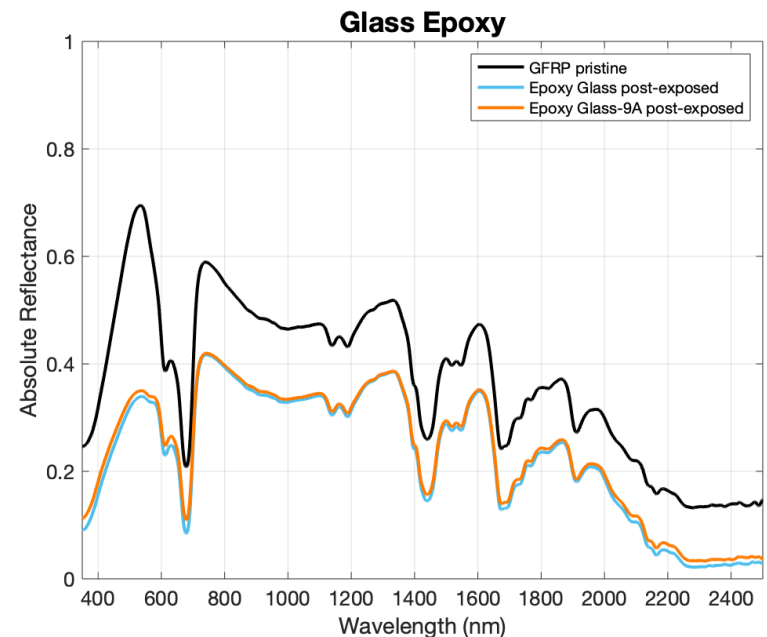
Glass Fiber Reinforced Polymer (GFRP)

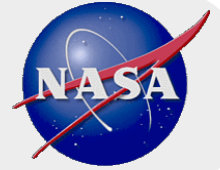
- **G-10/FR4 Glass Epoxy**

- Organic spectral features noted, unlike previous carbon fiber polymer, glass fiber exhibits many features in the VIS-NIR
- Due to blue/green pigment used in manufacturing, it peaks around 500–550 nm
- C-H doublet 1120 nm, 1200 nm; O-H or C-H 1450 nm, C-H 1690 nm, O-H 1900 nm
- Electron bombardment appears to decrease the overall reflectivity across the entire spectrum



Credit: NASA

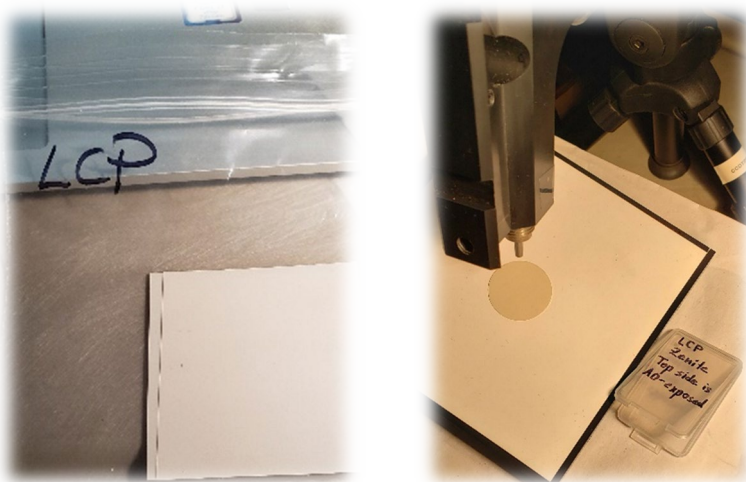




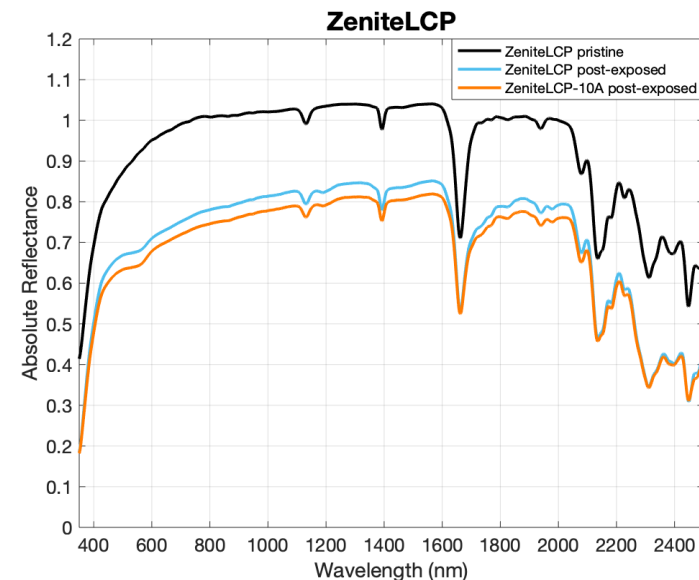
Liquid Crystal Polymer (LCP)

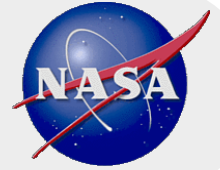
- **Zenite ® LCP**

- Visibly white, as evidenced by increased reflectivity at 400 nm
- Absorption feature near 1100 nm typically associated with Si
- Organic features present at 1400 nm, 1900 nm, 2100 nm, 2300 nm, and 2400 nm
- Electron bombardment appears to decrease the overall reflectivity across the entire spectrum (similar to CFRP)



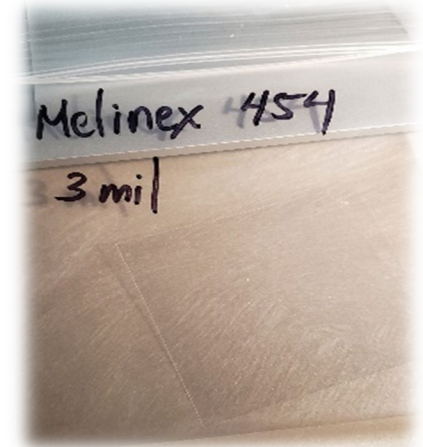
Credit: NASA



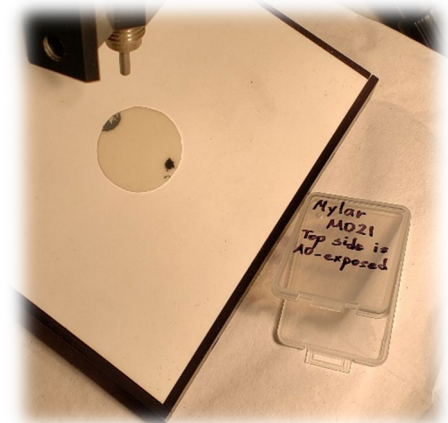


Polyethyleneterephthalate (PET)

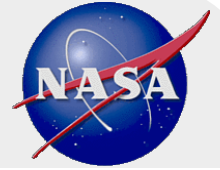
- PET films typically used in multi-layered insulation as passive thermal control, limiting the radiative heat transfer
- **Melinex[®] 454**
 - Transparent (9 and 10 mil)
 - <https://usa.dupontteijinfilms.com/wp-content/uploads/2017/01/454-Datasheet.pdf>
- **Mylar[®] M021**
 - Visibly white (3 and 5 mil)
 - https://usa.dupontteijinfilms.com/wp-content/uploads/2017/01/MO21_Datasheet.pdf



Credit: NASA



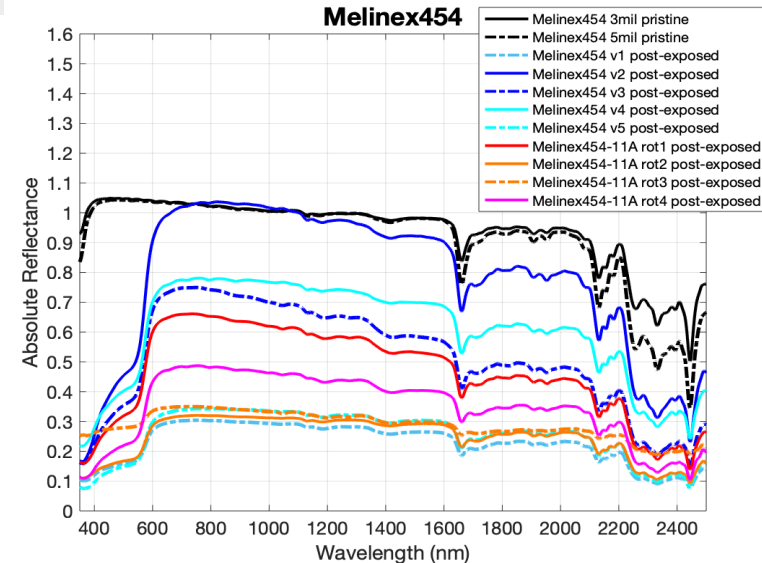
Credit: NASA



Polyethylene terephthalate (PET)

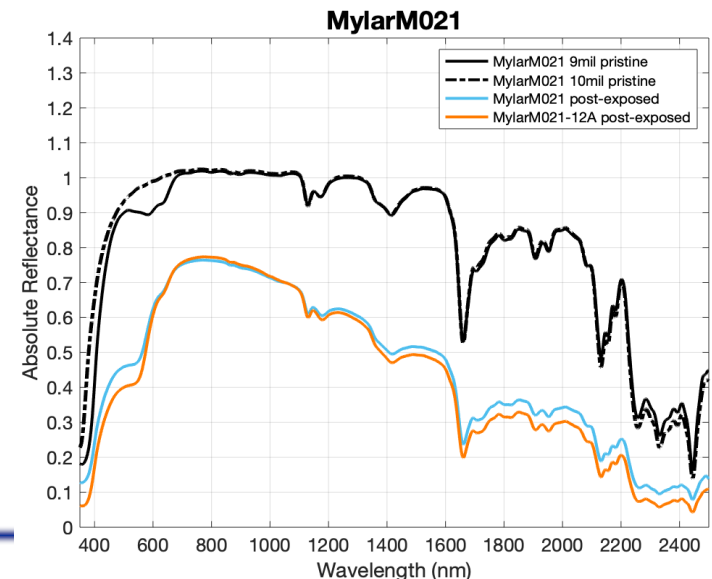
• Melinex 454

- **Pristine:** transparent material that is overly featureless in the visible regime with the small bandgap noted at ~350 nm, C-H or O-H bond triplet near 2100 nm, and C-H near 1650 nm and 2300 nm. The 2450 nm feature present in both PET samples is consistent with C-O or O-H bonds in organic materials, note PET is constructed with C-H-O bonds ($C_{12}H_{14}O_4$)
- **Exposed:** 400–600 nm feature due to adhesive, decrease 35% to 70% decrease in overall reflectivity

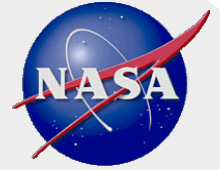


• Mylar M021

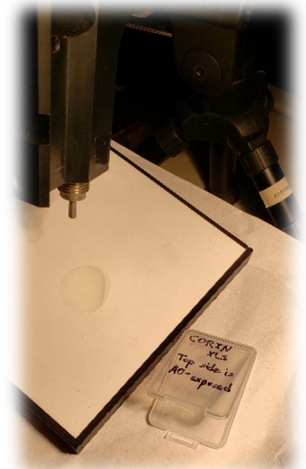
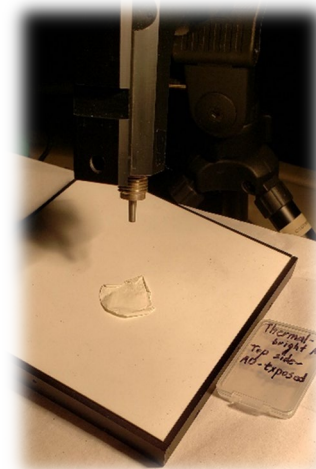
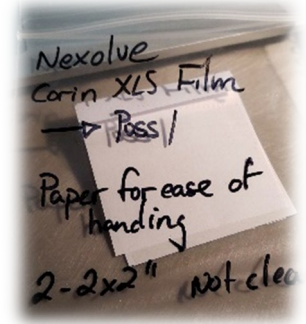
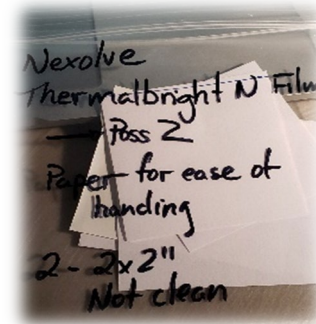
- **Pristine:** 450–400 nm bandgap due to white color, H₂O (1400 and 1900 nm), C-H or O-H bond triplet near 2100 nm, and C-H near 1650 nm and 2300 nm. 9 mil sample showed an absorption feature ~ 600 nm, also noted in white paints and previously measured Mylar samples
- **Exposed:** approximate 20% decrease in peak reflectance near 700 nm, overall exposed samples have consistent features with pristine



Polyhedral Oligomeric Silsesquioxane (POSS)

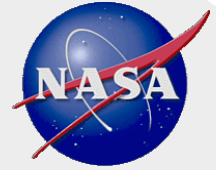


- **Corin[®] XLS**
 - NeXolve's AO-resistant CORIN[®] XLS, a transparent sprayable polyimide with POSS additives, provides highest AO durability polyimide from company and stability to solar radiation
 - <https://nexolve.com/advanced-materials/clear-colorless-polyimides/>
- **Thermalbright[®] N**
 - Colorless polyimide with POSS additives, AO resistant material, high temperature durability and highly reflective
 - <https://nexolve.com/advanced-materials/white-polyimides/>

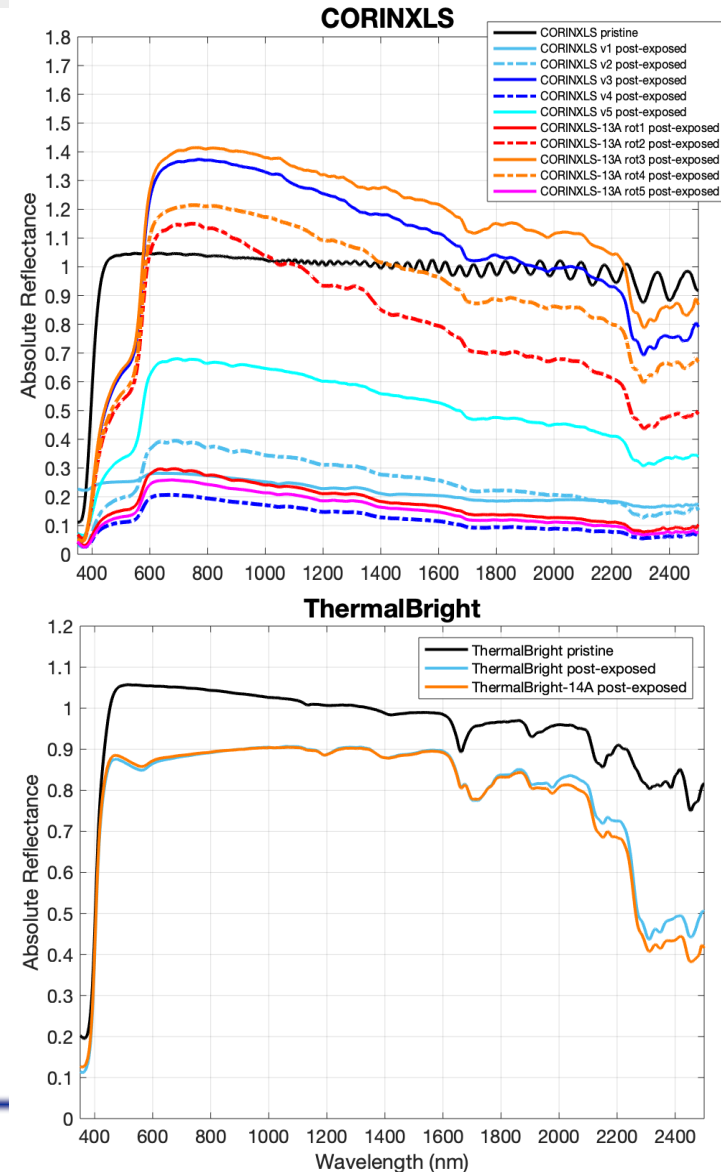


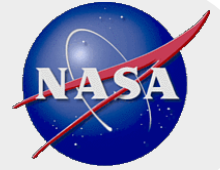
All Images Credit: NASA

Polyhedral Oligomeric Silsesquioxane (POSS)



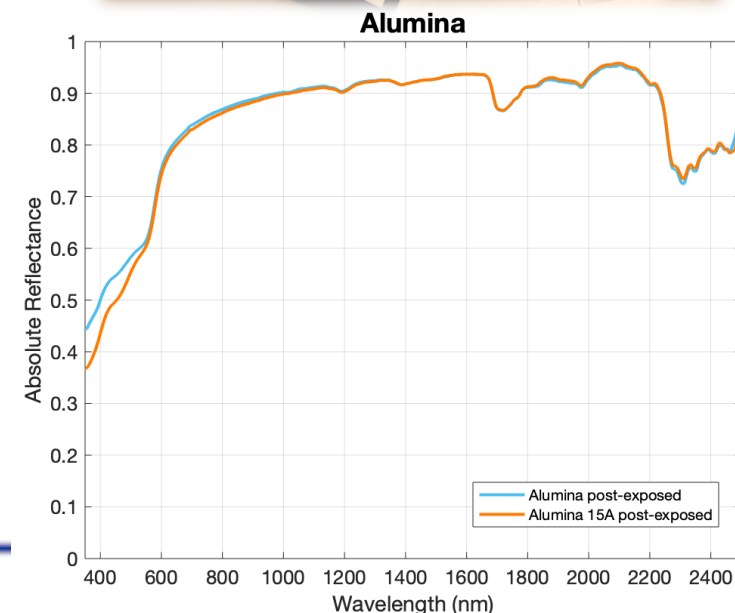
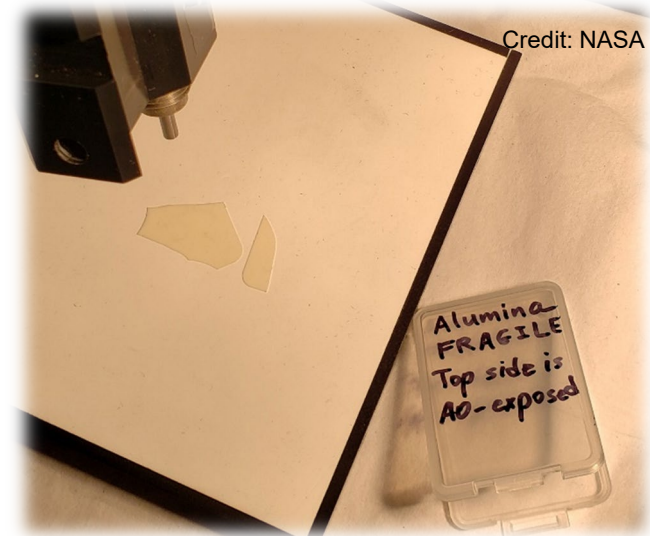
- **Both materials**
 - extremely thin, difficult to handle
 - showed variations due to exposure, specifically around C-H bonds
- **Corin XLS (0.6 mil)**
 - **Pristine:** flat response, notable interference, no organic features
 - **Exposed:** false feature near 400–600 nm due to adhesive, variations in reflectivity (highly specular) and significant decrease as the sample was rotated. Additional features near 1700 nm and 2300 nm associated with C-H
- **Thermalbright N (0.8 mil)**
 - **Pristine:** notable bonds C-H 1650 nm and 2300 nm, weak O-H 1900 nm, and C-H or O-H near 2100 nm
 - **Exposed:** approximate 10% decrease in reflectivity, C-H bond much deeper in exposed samples

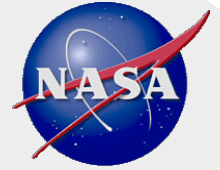




Aluminum Oxide (ALUM)

- **Alumina**
 - When used as a ceramic provides a high-melting point, resistant to corrosion, and serves as a protective layer for aerospace applications
 - Serves as AO-resistive optical standard for MISSE *in-situ* measurements
- **No pristine measurements were acquired in the OMC**
- **Both spectra post-exposed are in good agreement, with an overall high reflectivity across spectrum**
- **Feature at 400–540 nm associated with underlying adhesive (3M copper tape)**
- **Steady increasing slope in visible with overall 90% reflectivity common on white organic materials (i.e., paints)**
 - In the absence of atmosphere and without the adhesive, this material is expected to show spectrally flat response near 90+% reflectance
- **O-H bonds present at 1400 nm and 1900 nm**
- **C-H bonds present at 1650 nm and 2300 nm**





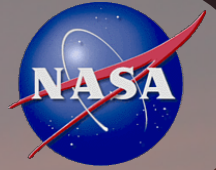
Conclusion/Forward Plans

- **Assessment:**

- The focus is to baseline 15 modern spacecraft materials of interest using laboratory characterization in pristine state and after electron bombardment to compare with in situ measurements acquired on MISSE
 - PMDA materials (7 total copper, white, and black), overall exhibited decrease in reflectivity, but two of the copper Kapton samples (TF and HN) and white Kapton sample (CS) showed an increase in reflectivity, in addition, those same samples showed variability with rotation in the illumination set-up
 - CFRP sample increased in reflectivity or relatively constant/with minor decrease, a function of the sample rotation after electron bombardment
 - GFRP & LCP materials both showed a decrease in reflectivity over the entire spectrum after electron bombardment
 - PET overall decrease in reflectivity after exposure, but the Melinex showed variations in reflectivity with sample rotations
 - POSS the thinnest materials, CORIN XLS increased and decreased in reflectivity after exposure as a result of rotating the sample, but the Thermalbright showed an overall decrease
- Overall, the electron bombardment does affect the reflectance of these samples and a small subset appear to vary based on the illumination set-up

- **On-going work/Forward Plans:**

- AO exposure characterization
- Conductivity measurements at AFRL post-AO
- Prepping for MISSE launch



Thank you

Any Questions?